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(54) Device for optical measurement of distances and spatial coordinates

(57) For the measuring of distances and spatial coordinates of points on an object and/or their movements, a device is proposed whereby, making use of imaging triangulation methods, the object being measured is illuminated with structurized light, and various light patterns that are already arranged in true phase on a common carrier are projected one after the other onto the object with a definite phase relationship. The device makes possible a simple, miniaturized design for projection instruments, while at the same time the parameters of the projected light structures can be adapted in broad limits to the particular problem.

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## Description

Known devices based on imaging triangulation methods for measuring of spatial coordinates each have their characteristic drawbacks, which at times greatly restrict their use in practical applications. These restrictions result primarily from the nature of the projection technique used. The device according to the invention avoids these difficulties by a novel projection unit, in which the light structures being projected are placed on a common carrier with definite phase position.

The invention relates to a device according to the preamble of Claim 1 for optical measuring of distances and spatial coordinates of object points or their displacements, making use of imaging triangulation methods in which the object being measured is illuminated with structurized light patterns, and these projected object rasters are recorded by an observation system with a camera, arranged at an angle to the direction of illumination and evaluated according to the laws of triangulation, with processing of the information from several object rasters.

A method of this type is known from the literature (Breuckmann, Lübeck, VDI-Bericht 679, 1988) as the phase shift method and it is described in detail in US Patent 4,641,972. A major problem of the phase shift method results from the fact that the absolute order of the striated pattern cannot be readily detected at any given point of the object and therefore one can generally only measure relative distances or object coordinates.

In EP-0 379 079 B1 a method is described with which this drawback can be avoided. For this, a number  $n$ ,  $n \geq 2$ , of brightness-modulated light structures with different period lengths are projected consecutively onto the object, so that several object rasters can be detected by the camera. For each object raster, a phase shift evaluation is

performed. In this way, for each object point one calculates a set of  $n$  phase values, from which the absolute spatial position of the object point can be uniquely determined. One difficulty in this method consists in that the phase position of the individual light structures placed in the projection beam path is not automatically defined sufficiently, with the consequence of possible systematic measurement errors. Therefore, EP-0 379 079 B1 also describes a device for solving these problems.

In this case, the light structures being projected are arranged as a ruled grating on a common carrier, where reference marks are additionally applied, relative to which the ruled gratings have a definite phase position. With the help of a shift unit, the common carrier can be moved, whereupon the phase position of the individual ruled gratings is checked and controlled in terms of the reference marks. But for this, additional means have to be provided for a high-precision shift unit and phase regulation, especially when working with ruled gratings having high density of lines, as are required for a miniaturized version of the projection unit.

Another topometric method for spatial coordinate determination is based on the so-called coded light approach (Wahl, Eighth DGAM Symposium, 1986). A configuration especially suitable for the practical implementation of this method works with a programmable LCD projector for generating the coded light structures. The essential drawback of this method is its relatively low resolution, which is not adequate for many application instances.

In other sources (DE 41 20 115 A1), (Krattenthaler, Mayer, Duwe, 1993), (Halbauer, graduate thesis 1993), a method is described that combines the advantages of the phase shift method and the coded light approach, while avoiding their drawbacks. A practical embodiment of this method can

likewise be realized with an LCD projector to create the necessary light structures. A serious drawback results from the limited resolution of the LCD display, as well as its relatively large construction. Measuring systems for spatial coordinate determination based on LCD displays are therefore restricted in their range of applications, especially when a small construction with high measurement accuracy is demanded.

Accordingly, the goal of the invention is to create a device which avoids the difficulties inherent in the mentioned designs, while at the same time preserving and/or combining the advantages of the individual methods.

The invention's solution to this problem consists in the characterizing features of Claim 1; advantageous embodiments of the device according to the invention are described in the dependent claims.

The device according to the invention is thus characterized in that the projection gratings required to produce different light structures are arranged on a common carrier already with defined phase relationship, and the carrier can be moved in true phase into the projection beam path in order to project the particular light pattern required. The carrier can be, for example, a glass plate coated with a chrome layer, on which the individual projection gratings are exposed. With the methods familiar from semiconductor processes, grating structures with high line density, variable line spacings and intensity distributions, as well as defined phase position can be realized with very small dimensions.

An advantageous embodiment of the device according to the invention is presented in dependent Claim 2. Here, line gratings are used, being arranged one over the other in proper phase as regards their grating structure—as shown for example in Fig. 1. In order to bring the individual line gratings 1, 2, 3 into the beam path of the projection unit, the

common carrier 4 is moved perpendicular to the grating structure.

According to the dependent Claims 3-4, the exact orientation of the direction of movement perpendicular to the grating structure and therefore the true-phase projection of the line gratings can be additionally ensured by an adjustable mechanical precision guide 5 as well as a reference stripe 6 arranged on the grating.

Dependent Claim 5 describes a further advantageous embodiment of the device according to the invention, which enables an especially compressed storage of line gratings, so that projection devices with very small construction are made possible. Since—as depicted in Fig. 2—all of the information in line gratings is contained in a cross section perpendicular to the trend of the lines, it is sufficient to expose a narrow projection band 7 with the required line structure on the carrier. Using a suitable cylindrical optics 8 or anamorphic projection, the projection band can be broadened with the required projection relationships and projected into the object plane 9.

A particular advantage of the device according to the invention consists in the fact that a large number of different projection gratings can be stored on the carrier, and the grating parameters of the individual gratings can vary in broad limits. The dependent Claims 6-12 refer to advantageous configurations that can be realized by choice of the projection grating.

A further advantageous configuration is described in dependent Claim 13. Here, the beam paths—as shown in Fig. 3—from projection unit 10 and/or viewing system 11 are guided across mirrors 12 so that an effective triangulation base 13 is produced, which is larger than the structural length 14 of the device.

This enables a further reduction in the structural size and weight of the device according to the invention, without reducing

the measurement accuracy or resolution, an advantage which is especially important for integration in handling systems with limited load.

According to dependent Claim 14, in another advantageous embodiment of the device according to the invention, a color camera is used, which records not only the line pattern but also the texture and color of the object.

Hence, an expanded database is available to create a true-to-life image of the measured object. For example, this can be either a real model or a computer-generated picture in virtual reality.

### Claims

1. Device for measurement of distances and spatial coordinates of object points and/or movements of object points, making use of imaging triangulation methods (topometric methods), such as projected-fringe, moire, or grey code techniques, with

- a projector for projection of structurized line patterns
- a number of projection gratings with differently encoded light structures
- a viewing system for observing the light structures projected onto the object
- a detection and evaluation unit, with which the absolute position of the object points being measured is determined from the object rasters observed by the viewing system
- a shifting mechanism

characterized in that

- the individual projection gratings are arranged on a common carrier with defined phase position and
- the carrier is moved by means of the shifting mechanism in the projector so that the individual phase gratings are projected in true phase into the measurement space.

2. Device according to Claim 1, characterized in that line gratings are used for the projection, which are arranged one over the other—in relation to the grating structure—and the shifting of the carrier is perpendicular to the grating structure.

3. Device according to one of Claims 1 to 2, characterized in that an adjustable mechanical guide makes possible a phase-true shifting.

4. Device according to one of Claims 1 to 3, characterized in that a reference stripe is placed on the grating carrier for adjustment and regulation purposes.

5. Device according to one of Claims 1 to 4, characterized in that line gratings for the projection are stored on the carrier, compressed perpendicular to the grating structure, and the gratings thus compressed are projected by a suitable imaging into the measurement space, and the grating can be expanded out once again by selecting different imaging scales in the x and y directions.

6. Device according to one of Claims 1 to 5, characterized in that the coding of the light structures is done by the coded light approach.

7. Device according to one of Claims 1 to 5, characterized in that the coding of the light structures is done by the phase shift method.

8. Device according to one of Claims 1 to 5 and 7, characterized in that light structures with sinusoidal intensity distribution are projected.

9. Device according to one of Claims 1 to 5 and 7 to 8, characterized in that the coding of the light structures is done such that, according to the phase shift method, rasters with different grating periods are projected, and the ratio between the grating periods is chosen so that a definite triangulation is possible.

10. Device according to one of Claims 1 to 9, characterized in that the coding of the

light structures is done by a combination of phase shift method and coded light approach.

11. Device according to one of Claims 1 to 5, characterized in that color-coded light patterns are used.

12. Device according to one of Claims 1 to 11, characterized in that the coding of the light structures is done by a combination of phase shift method, coded light approach, and color coding.

13. Device according to one of Claims 1 to 12, characterized in that the beam paths from projection unit and/or viewing system are guided across mirrors so that an effective triangulation base is produced, which is larger than the structural length of the device.

14. Device according to one of Claims 1 to 13, characterized in that a color camera is used in the viewing system, which observes and detects not only the projected light structures, but also the texture and color of the object.

[Plus 3 pages of drawings]